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HIGH POWER SUBMILLIMETER AND INFRARED RADIATION FROM INTENSE RE--ETC(U)
1981 S P SCHLESINGER, T C MARSHALL AFOSR-80-0118

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Interim Scientific Report

to

Air Force Office of Scientific Research

"High Power Submillimeter and Infrared Radiation from Intense Relativistic Electron Beams"

Research Conducted Under: Grant AFOSR—80-0018

Period Covered: 1 January 1980-31 December 1980

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Professor of Electrical Engineering

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Table of Content

I. Introduction

We present herein a brief summary of research conducted during the 1980 calendar year under AFOSR [redacted] 80-0118.

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The first quarter of 1980 was spent installing and testing the newly acquired long-pulse well-regulated Physics International Pulserad 220 unit (1 Mev. 20 KA 100 0 nsec). [redacted] The balance of the year was spent on the first phase of the FEL long pulse oscillator expriment and the beginnings of an [redacted] investigation of the FEL amplifier. Theoretical work included an exact analysis of particle dynamics in a true wiggler and the formulation of a simulation of a pump-oscillated test particle in a plasma background, the latter study yielding new insights into finite Larmor radius effects.

Wavelength and power were measured as a function of electron energy and current.

II. Experimental Research

A. Oscillator.

In April, 1980. we reassembled the FEL oscillator in a configuration similar to that used in the first NRL-Columbia experiments of 1978. In addition to permitting a more detailed study of certain phenomena observed in the early effort, we now have use of our Pulserad 220G machine, in which the Diode voltage is reasonably flat ($\lesssim$ 2%) over a long period (80-150 ns). These experiments continued until November, 1980, and in their course we established the following:

(1) There is no problem in operating an intense electron beam, cold enough to sustain laser oscillation, for 150 nsec.

(2) "Superradiant" levels of noise emission from the system are small

compared with other beam noise for $\lambda > 1$ mm.

(3) FEL-oscillator operation was conducted at $\lambda_s = 1.0$ and 0.6 mm, as observed by a Fabry-Perot interfermeter. Adding this data to the data of prior experiments, we now have a curve showing that $\lambda_s \sim 1/\gamma^2$ for $0.4 < \lambda_s < 1.7$ mm, as expected from stimulated scattering. The spectrum shows $\frac{\Delta\lambda}{\lambda} \lesssim 1\text{-}2\%$, whereas the superradiant spectrum is very wide ($\sim 13\%$).

(4) The power emitted from the laser increases as λ_s decreases; we have observed stimulated emission up to $\sim$ 1 MW, as detected by a calibrated crystal. This estimate is also consistant with a measurement made by a pyroelectric element. Calibration and measurement of insertion losses was done with a $\lambda =$ 1 mm Carcinotron and a $\lambda =$ 1/2 mm CH_3F laser. The coupling from the laser cavity is estimated to be $\sim 5\%$.

(5) Signal analysis permitted observation of cavity losses ($\sim$30-40% pass), filling factor ($\sim$0.3) and single-pass gain ($\Gamma L \sim 1.5 > \Gamma L$ threshold ~ 1). Output from the laser usually consists of a single spike, about 40-50 ns long, although two or three spikes have been observed. It is not yet clear whether these "spikes" are due to fluctuations in electron beam voltage or whether they are caused by a nonlinear mechanism common to conventional lasers involving the pump, scattered wave intensity, and the FEL gain (the latter is sensitive to the beam energy).

(6) In order to evaluate the signal data better, we have begun a "Fox-Li" type numerical analysis of the FEL resonator-including the waveguiding properties of the drift tube and the separation of the mirrors from the drift-tube. This should provide us with a quantitative picture of the radiation structure in the resonator.

B. Amplifier

We have initiated our program to attempt to measure the dependence of amplification of an input signal on the electron beam's energy. The output of an optically pumped far-infrared laser is optically coupled into the diode and reflected onto the electron path by a mirror in a hollow cylindrical cathode. Construction and testing of the submillimeter source for the FEL amplifier experiment has proceeded parallel to the oscillator experiment. The CO_2 TEA laser "pump" was borrowed from the Lincoln Laboratory and the design of the FIR cavity was supervised by Dr. H.R. Fetterman of Lincoln. After the completion of the oscillator in November the amplifier source was put in place and the extra mirrors, cathodes, ports and undulators were built.

Our first choice of FIR laser medium was the readily accessible and inexpensive $C^{12}H_3F$, because of the separation of its 496 μm output from the mm-cm cyclotron maser radiation which accounts for a "noise" background in any perturbed-IREB experiment. Given the voltage limitations of our Pulserad 220 G ($\gamma \leq 3$), we would need a 6 mm undulator period-or smaller- to amplify 496 μm radiation. The 6 mm undulator we built could not withstand even half the pulsed current that was required for modest amplifier gains. We are thus forced to work with $C^{13}H_3F$ and a wavelength of 1.222 mm.

Here, the cyclotron maser does account for a high-level background. In an effort to operate above this background we are running the CO_2 TEA self mode-locked and with the same cavity length as the FIR system so that we obtain regular, high-power spikes separated by 12 ns. To determine gain we will measure the FIR radiation before and after it is passed through the e-beam via a beam-splitter. The amplified signal will be measured in a grating spectrometer with resolution ~1%. Both detectors are Schottky-barrier diodes and have been supplied by Dr. Fetterman.

III. Theoretical Research

A. Analytical studies

A study was conducted of electron trajectories and their stability when subjected to the magnetostatic fields of a free-electron laser. These include both the uniform guide magnetic field and the spatially periodic wiggler field. The usual model of a wiggler field has only axial dependence and only transverse components; except very near the axis of the drift tube, this violates Maxwell's equations and is hence unrealizable. The motion of electrons is affected by the radial variation and the periodic axial field component of a realizable wiggler. Exact helical orbits were found for relativistic electrons in combined uniform guide field with realizable wiggler, in cylindrical geometry. It was discovered that the parameter that measures the size of the orbital helix also measures the imparted quiver motion on which the laser gain depends, which explains the need for a realizable wiggler theory in practical cases. A perturbation and stability analysis of the orbits was made, giving the trajectory of an electron that starts from any position and velocity in combined guide and wiggler fields, with corrections for realizability and harmonics of practical bifilar wiggler windings. The helical orbits were found to be either strongly unstable or else exhibit secular growth in time.

The exact helical orbits are being studied further and beams of electrons in realizable wigglers are under investigation to develop corrected laser gain characteristics.

B. Particle simulations

The orbit of a test electron moving down a wiggler has been studied numerically; included in the analysis are: (a) finite beam current and space-charge; (b) finite radial and axial field inhomogeneity due to the wiggler; (c) transient effects entering the wiggler. We have examined the "temperature" of the test electron by calculating $\langle \Delta\beta_z \rangle = \langle \frac{\Delta V_z}{c} \rangle$, the velocity fluctuation of the electron along its orbit (this is relevant to the temperature of the ensemble, which determines the applicability of cold beam (Raman) physics to this FEL situation). It is found that one can prevent the beam energy spread from growing beyond $\sim 3\%$ if the wiggler amplitude is kept small ($B_\perp \lesssim 1/2$ kG) and one avoids either the "magnetoresonance" ($2\pi\beta c/\ell = \frac{eB_o}{\gamma mc}$) or its harmonics. Harmonic effects ($2\pi\beta c/\ell = n \cdot \frac{eB_o}{\gamma mc}$) involve a finite Larmor radius interaction between the particle and the inhomogeneous fields. The range of guiding magnetic field (B_o) in which the beam deteriorates due to this interaction becomes rather broad because of the long extension of the wiggler (~ 60 cm).

IV Publication and Talks

A. Published

1. "The Collective Free Electron Laser", D.B. McDermott and T.C. Marshall, p. 509, in "Physics of Quantum Electronics, vol. 7, "Free Electron Generators of Coherent Radiation", editors Jacobs, Pilloff, Sargent, Scully, and Spitzer. Addison-Wesley (1980).
2. "The Free Electron Laser - A High Power Submillimeter Source", T.C. Marshall S.P. Schlesinger, D.B. McDermott in Advances in Electronics and Electron Physics, vol. 53, p.47; C. & L. Morton editors; Academic Press, (1980).

3. "Enhancement of Stimulated Raman Backscattering by Magnetoresonance Effects" D.S. Birkett and T.C. Marshall, Phys. Fluids 24, 178 (1981)

B. To Appear

1. "Free Electron Lasers Based Upon Stimulated Raman Backscattering: A Survey", T.C. Marshall, Plenum Press, Majorana Series (1981), S. Martelluci, editor.

2. "A Submillimeter Free Electron Laser Experiment", D.S. Birkett, T.C. Marshall, S.P. Schlesinger, D.B. McDermott. Special FEL issue, IEEE J. Quant. Electr. July 1981 , A. Szöke, editor.

3. "Electron Orbits and Stability in Realizable and Unrealizable Wigglers of Free-Electron Lasers", P. Diament. Physical Review A. (1981).

C. Technical Talks

	Author(s)	Title	Meeting	Abstract Reference
1.	McDermott (Invited)	"Collective Free Electron Laser Experiments"	APS/Chicago 1/80	Bull. APS 25, (1980)
2.	Marshall (Invitied)	"The Raman FEL" (A Series of 3 lectures)	Erice Conf. Majorama Summer Sch. Scicil 8/80	
3.	Diament	"Realizable vs. Unrealizable Wigglers for Free-Electron Lasers"	APS/Plasma 11/80	Bull. APS 25, 989 (1980
4.	Birkett, McDermott Marshall, Schlesinger	"Free Electron Laser Oscillator-New Results"	APS/Plasma 11/80	Bull. APS 25, 989 (1980)
5.	Grossman, Marshall	"Orbits of a Test Electron in a Wiggler"	APS/Plasma 11/80	Bull. APS 25, 989 (1980)

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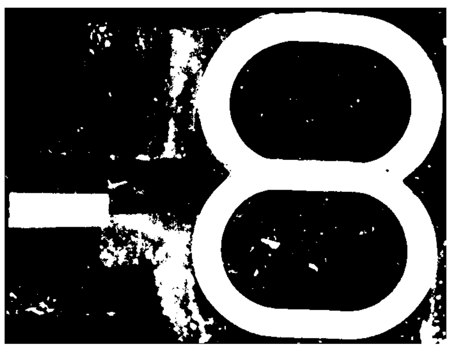
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